



UNITED STATES AIR FORCE IERA

Assessing Worker Exposures During Abrasive Blasting: Industrial Hygiene Field Guidance for Bioenvironmental Engineers

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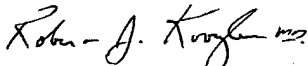
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ASSESSING WORKER EXPOSURES DURING ABRASIVE BLASTING: INDUSTRIAL HYGIENE FIELD GUIDANCE FOR BIOENVIRONMENTAL ENGINEERS

INTRODUCTION

Aircraft, aircraft components, and aircraft support equipment are predominantly constructed of metallic and composite materials. The surfaces of these aerospace materials are subjected to man-made and natural environments that degrade the material integrity [1]. Metallic materials are subject to corrosion while composite materials can delaminate [2]. Organic coatings, such as primers and paints, are the principal means of protection for these surfaces. When coatings are damaged, they must be removed and reapplied to continue to provide protection of the substrate and improve the material's aesthetic qualities and stealth characteristics.

The most common methods for removal of organic coatings are chemical and mechanical. In the U.S. Air Force abrasive blasting is one of the most widely used mechanical methods to remove surface organic coatings, scale, and rust from aircraft surfaces and parts in preparation for subsequent finishing operations. Abrasive blasting is the most effective and economical method for this purpose [3]. The original abrasive material used when this process was invented in 1904 was sand. Although sand is still used extensively by manufacturing industries, its use in the Air Force is limited and has been superseded by other types of abrasives, including plastic media, walnut shells, wheat starch, sodium bicarbonate, aluminum oxide, and glass beads.

There are two main methods used in the Air Force to project the abrasive onto the surface material, namely compressed air and hydroblast (also referred to as "medium pressure water blasting"). In the compressed air system, the abrasive is forced into the throat of an abrasive blasting nozzle. Compressed air fed to the nozzle carries the abrasive onto the work surface. Hydroblasting uses a pressured stream of water to transport the abrasive; water pressures up to 15,000 pounds per square inch (psi) are possible. At operational bases, compressed air is the most common of the two methods, although hydroblast systems are becoming more prevalent (e.g., the "Aqua Miser" system, which is a small-scale hydroblast unit). Large-scale hydroblasting is usually reserved for logistics bases who perform full-aircraft coating removal as part of depot-level maintenance.

The principal health hazard associated with abrasive blasting is exposure to the blasting media and debris removed from the workpiece. Among this debris are metal alloys contained in the aircraft surface, such as chromium, nickel, and beryllium, and metals plated onto aircraft parts for corrosion purposes, such as cadmium. In addition, toxic materials in the surface coatings, such as hexavalent chromium and lead, can present inhalation hazards to workers.

In the past, it has been difficult to measure worker exposures during abrasive blasting operations. Accepted sampling methods for metals, such as filters in cassettes, results in rapid overloading and shredding of the filter by high-velocity particles projected into the inlet after rebound from the surface being blasted. In addition, non-inhalable particles larger than 100 micrometers (μm) are abundant during abrasive blasting and are easily captured by these sampling methods. Analysis of this non-inhalable dust can result in a considerable overestimation of worker exposures to airborne metals.

As a result of these concerns, the Industrial Hygiene Branch of the Air Force Institute for Environment, Safety and Occupational Health Risk Analysis (AFIERA) recently completed an Air Force-wide assessment of worker exposures during abrasive blasting operations. The study design, data analysis, and sampler development were accomplished in collaboration with researchers from the University of Cincinnati. We completed a series of field evaluations at Kelly, Robins, Hill, and Mountain

Home AFBs. Sampling results from the field evaluations are in Appendix A. This technical report summarizes our recommended sampling methodology, data interpretation, ventilation requirements, personal protective equipment, and workplace practices for abrasive blasting. The minimum recommended engineering controls and protective equipment requirements will be incorporated into T.O. 1-1-8, *Application and Removal of Organic Coatings, Aerospace and Non-Aerospace Equipment* by the Air Force Corrosion Prevention and Control Office.

NOTE: The primary emphasis of this technical report is on compressed air abrasive blasting, as it is the most common type of blasting Bioenvironmental Engineers will need to evaluate. A follow-on report on hydroblasting is planned.

DESCRIPTION OF ABRASIVE BLASTING OPERATIONS

Facility Description

Abrasive blasting uses compressed air to direct abrasive media toward the desired surface with a blast nozzle. To contain the abrasive media and generated dusts, blasting is predominantly accomplished in an enclosed facility of some sort. The blasting enclosures typically found in the Air Force are of two types: blasting cabinets, where the operator stands outside the enclosure, and blasting rooms, where the operator stands inside the enclosure. Abrasive blasting enclosures are manufactured in many different sizes, from blasting cabinets only large enough to enclose small parts to walk-in blasting rooms the size of an aircraft hangar.

Workers use blasting cabinets while either sitting on a stool or standing. The workers place their hands through arm portals into rubber gloves inside the cabinet enclosure. The worker places the parts being blasted into the cabinet through a door on the side of the cabinet. A typical blasting cabinet is shown in Figures 1 and 2 (exterior and interior views). In blasting rooms, the worker stands inside of the enclosure during blasting. The worker therefore must wear full-body protective equipment, including an abrasive blasting helmet. A common type of blasting room used in the Air Force is shown in Figures 3 and 4.

In general, blasting enclosures consist of a storage hopper, a media recovery system, a media separator, and a ventilation/emission control system [4]. Most blasting procedures work in the following manner. First, media is directed from the storage hopper through a compressed air blasting nozzle held by the worker (see Figure 5). The media abrades the surface or parts. The media, any coatings, and the substrate is partially broken down. In blasting cabinets, spent media falls through a grate the parts sit on and is recycled through the media recovery system. In blasting rooms, spent media falls to the floor. Some automated blasting rooms have grates in the floor; conveyors or augers transport the recovered media back to the hopper. Other walk-in enclosures, however, are not automated and workers must periodically shovel existing media into the recovery system during the blasting operation. The ventilation system collects abraded coatings and passes them through a cyclone. The cyclone separates the coatings from any blasting media also collected by the ventilation system. Separated media is either sent back to the storage hopper for reuse or collected for disposal. The abraded coatings are sent to an emission control system of some sort, such as an additional cyclone, where most of the waste particulates fall into a drum for later disposal. The air is then filtered before being exhausted to the atmosphere.

Process Description

Abrasive blasting operations vary somewhat across the Air Force. They usually consist, however, of the following sequential procedures.

Pre-blast Preparation: Removal of grease, oil, hydraulic fluid, and dirt from the surface to be blasted. Cleaning prevents contamination of the abrasive with water and other fluids. Structural Maintenance personnel may perform the cleaning procedure, but in some cases the agency responsible for the equipment will clean it, e.g., Aerospace Ground Equipment cleans aircraft support equipment using an aircraft soap, Wheel and Tire cleans wheels, Repair and Reclamation cleans brakes. A separate technical report will include complete field guidance on evaluating aircraft and aircraft parts washing. After cleaning, workers apply either masking or duct tape to certain areas requiring protection from the blasting media. Masking also protects interior areas from dust and abrasives.

Figure 1. Abrasive Blasting Cabinet (Exterior)

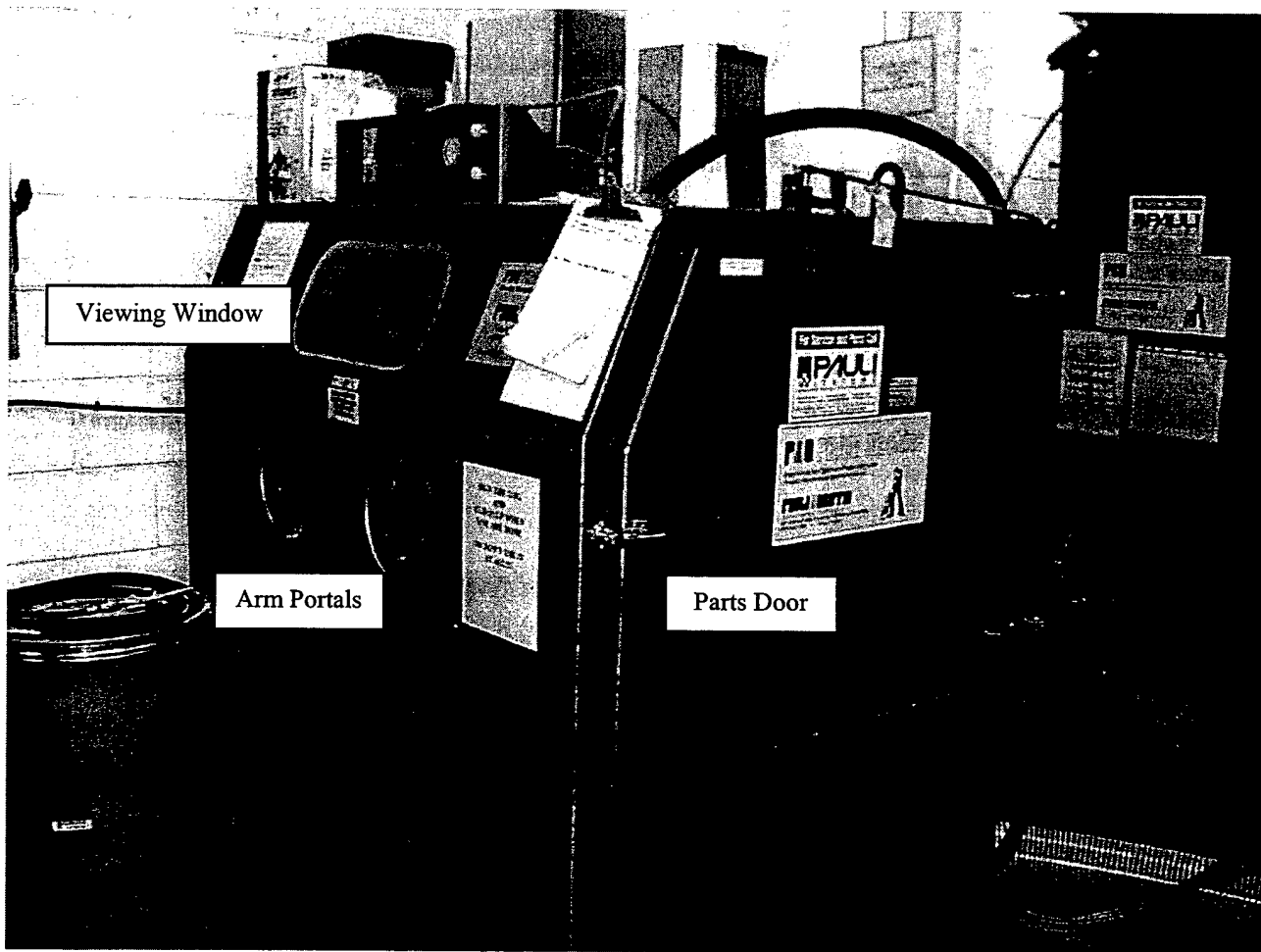


Figure 2. Abrasive Blasting Cabinet (Interior)

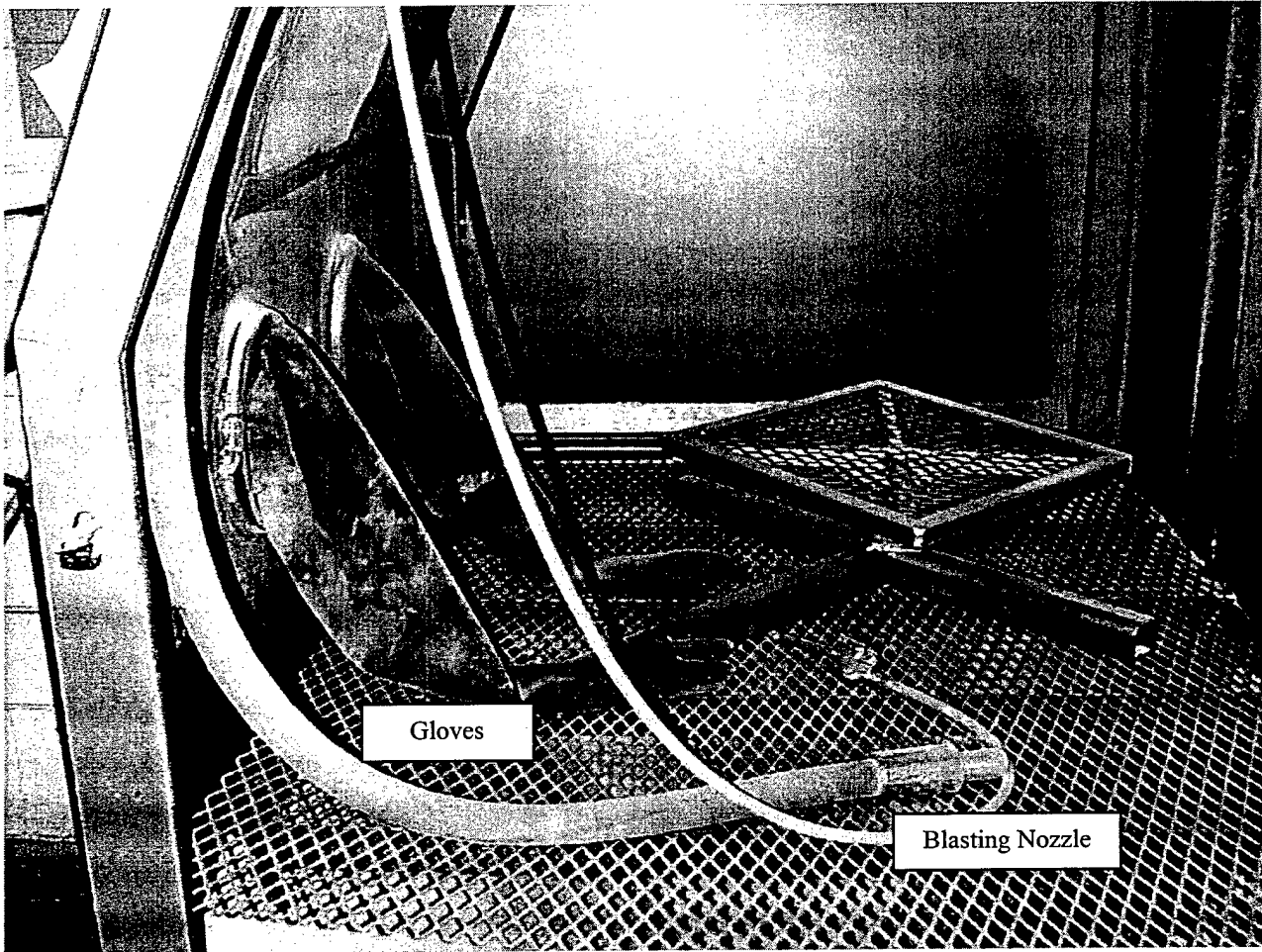


Figure 3. Abrasive Blasting Room (Exterior)

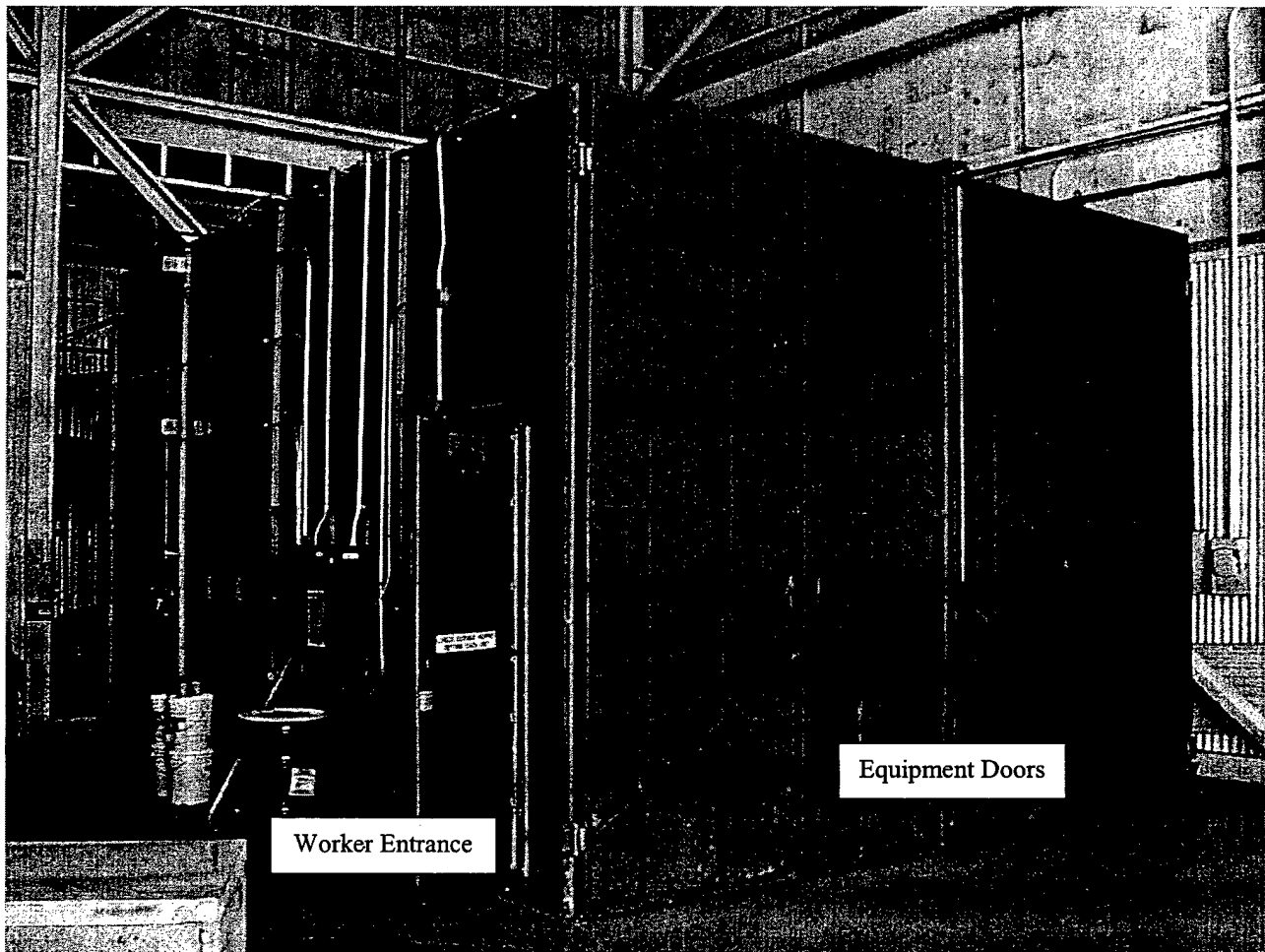


Figure 4. Abrasive Blasting Room (Interior)

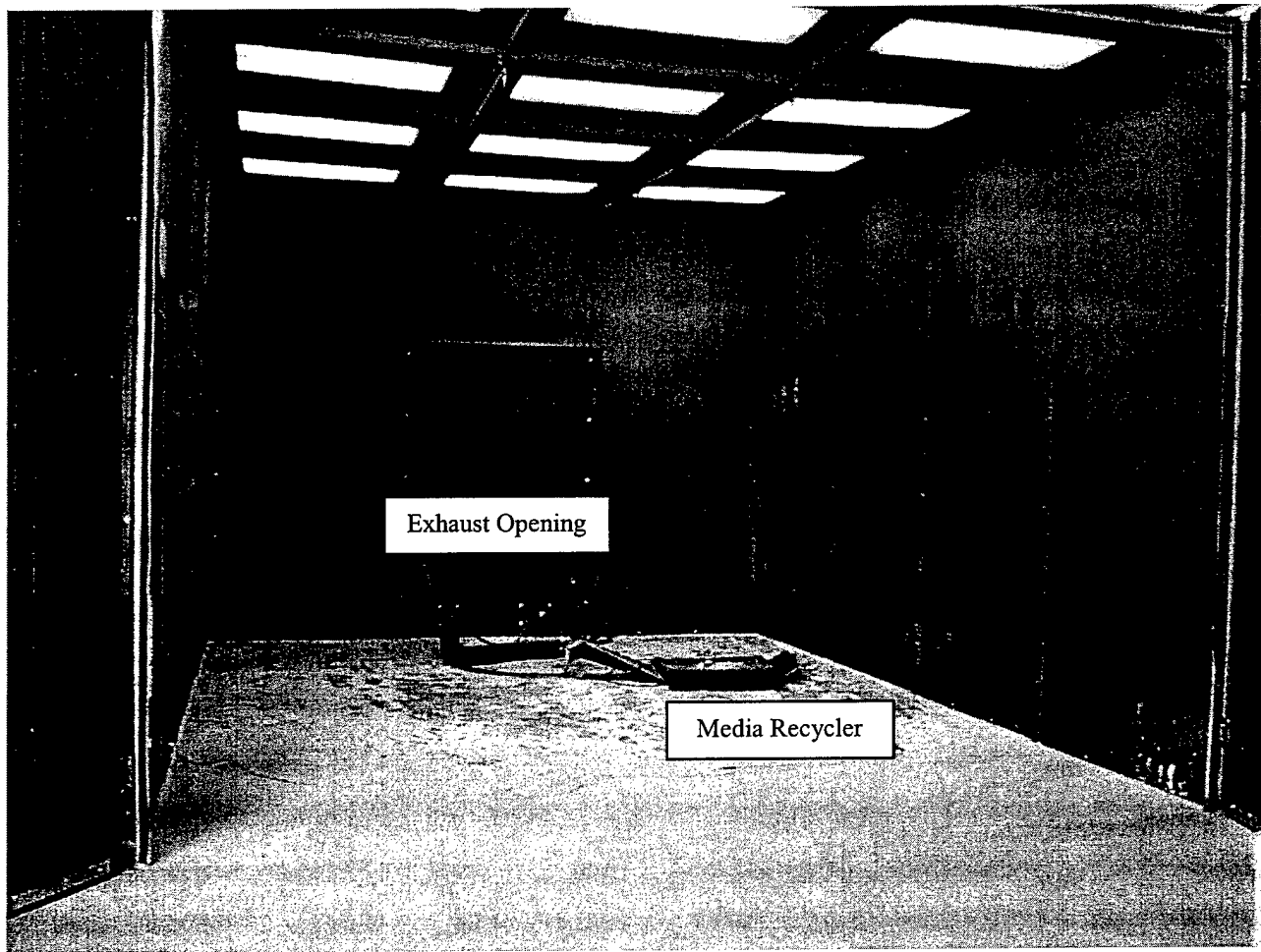
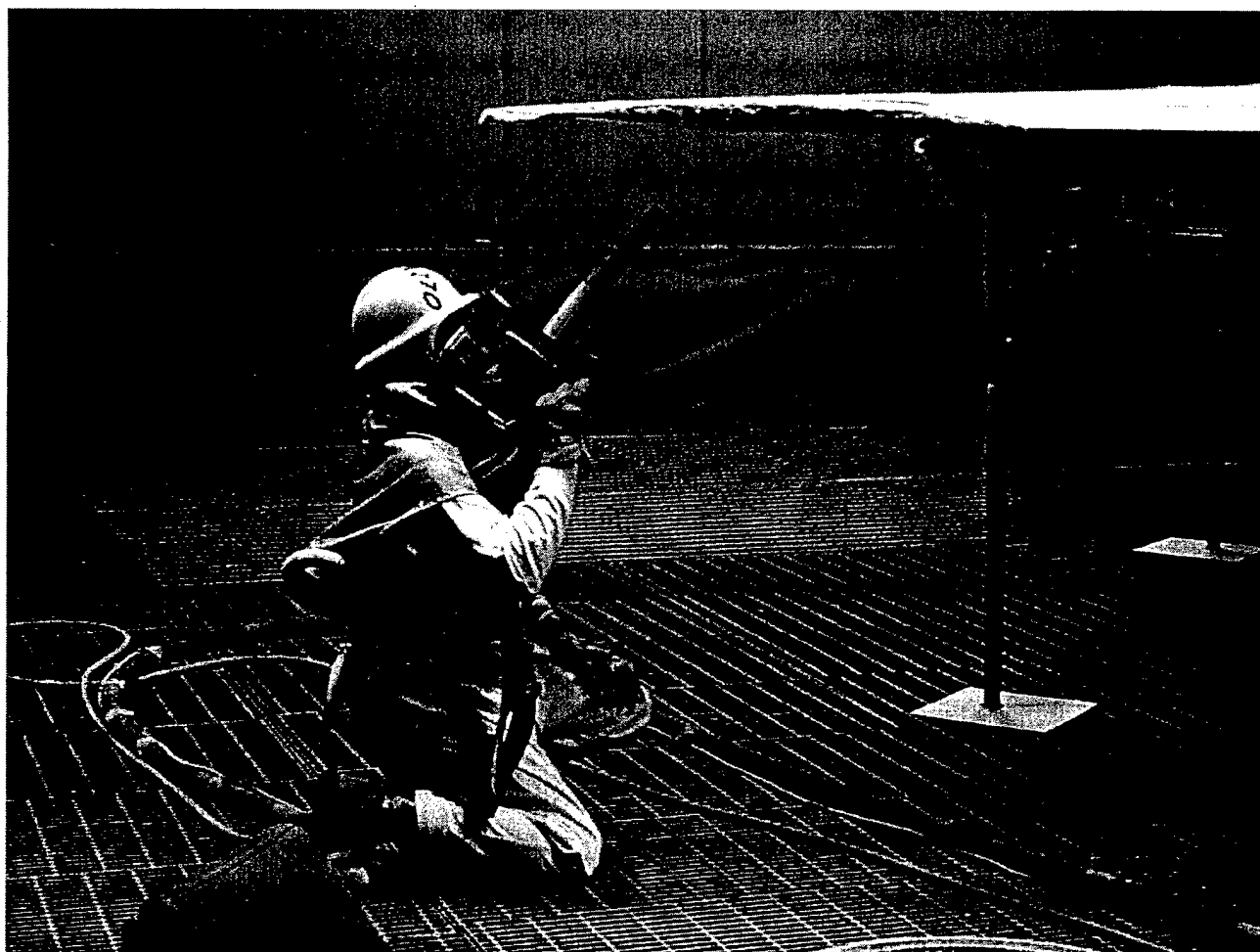


Figure 5. Worker with Blasting Nozzle



Refilling of blast media: Adding media to the blast system. The procedure involves opening a bag or barrel of abrasive and pouring the media into the storage hopper, usually located in or on the enclosure floor. Worker exposures are minimal; most blast media is outside the inhalable range and does not present an inhalation hazard during refilling.

Abrasive blasting: Use of pressurized abrasive media to remove coatings and corrosion. The worker first positions the parts in the blasting enclosure; aircraft and support equipment are generally towed into blasting rooms, while parts are carried in by the workers. Then, using a pressurized hose and blast nozzle, the worker directs the abrasive media onto the surface. Various media types, blast nozzle pressures, blasting angles, standoff distances, and dwell times are used, depending on the substrate blasted and the media used. In a blasting cabinet, the worker holds the blasting nozzle by hand; in a blasting room, the worker holds the blast nozzle either over the shoulder or at one side. Workers periodically reposition parts during the blasting operation so all surfaces are contacted by the abrasive. Significant worker exposures to metal-containing dusts occur during blasting room operations.

Post-blast cleaning: Removal of residual dust from the blasted surface. Workers either vacuum the surfaces or, as an alternative, use compressed air or water wash. Eye, dermal, and inhalation exposures to metal-containing dusts are possible.

Final finishing/clean-up: Removal of dust and residual blasting media from inside the blast enclosure and adjacent areas; removal of masking tape; cleaning of debris screens located above media storage hoppers. Depending on the design of the blast enclosure, some fugitive media and dusts may escape the blasting enclosure and require clean-up. Workers either dry sweep or vacuum areas in and around the blast enclosure after blasting. Workers may also vacuum, remove and empty debris screens. There is the potential for eye, dermal, and inhalation exposures to metal-containing dusts during clean-up if the dusts are re-suspended.

AIR SAMPLING METHODOLOGY

Parameters Influencing Worker Exposures

Abrasive blasting operations can expose workers to metal-containing dusts generated from metal surfaces and their coatings. Different substrates and coatings will contribute to different worker exposures. Many aircraft parts and equipment are constructed of high-strength steel or aluminum. We would expect exposures to iron to be higher when blasting uncoated steel parts and higher aluminum exposures when blasting aluminum parts. High-strength steel parts (such as landing gear) may have been plated with cadmium to prevent corrosion [5]. We would anticipate higher cadmium exposures when cadmium-plated surfaces are blasted than those that are not plated. Aluminum surfaces and parts may have been pre-treated with a conversion coating (also referred to as alodine). Alodine contains hexavalent chromium; this results in higher chromium exposures when blasting alodined surfaces. Aircraft surfaces and many parts are coated with a chromate-containing primer and therefore we would expect higher chromate exposures. Finally, we should see higher aluminum exposures when using aluminum oxide as the blast media than if we chose another blast media. Table 1 summarizes our sampling recommendations for abrasive blasting operations.

Particulate Distributions

Particulates generated during abrasive blasting procedures vary in size and form a particulate mass distribution (frequently referred to as the "total aerosol mass"). It is impossible to accurately measure the total aerosol mass if there is a wide range of particle sizes present in the distribution you're interested in, as the collection efficiency of samplers vary for different particle sizes [6]. Particles generated during abrasive blasting operations range in size from 1 to 1000 μm [7]. Therefore, in practical terms you can only accurately measure some portion of the entire distribution. There are three types of particulate distributions of interest to the industrial hygienist: the inhalable particulate mass; the thoracic particulate mass; and the respirable particulate mass [8]. These distributions are based upon the aspiration and deposition characteristics of the human respiratory tract. The primary distributions of interest during abrasive blasting operations are the inhalable and respirable mass. The inhalable mass is the portion of the total aerosol mass the worker actually breathes into the respiratory tract, while the respirable mass is that portion of the total aerosol that ends up in the gas-exchange region of the lungs.

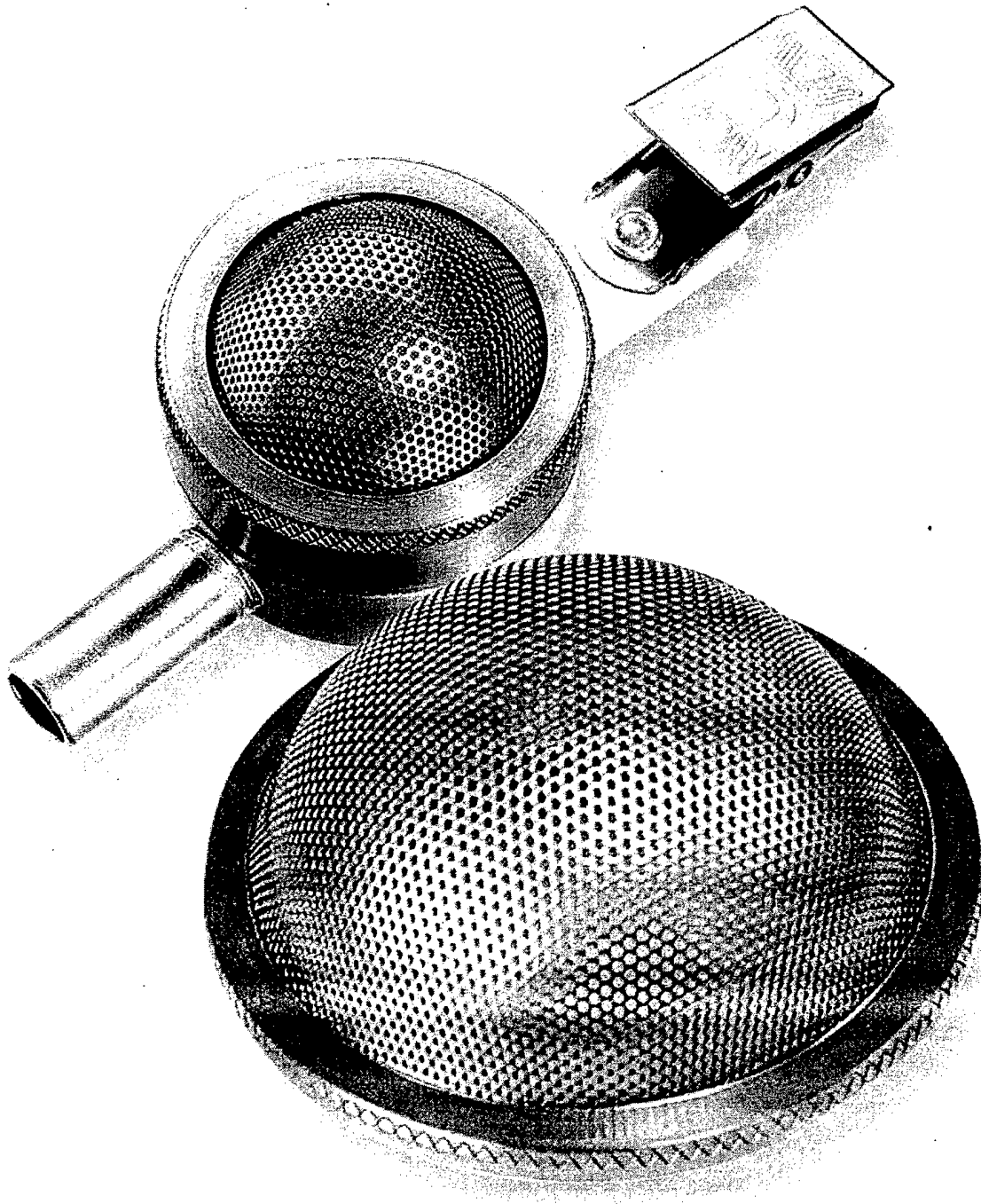
Inhalable Metal Particulates

Abrasive Blasting: Most filter samplers result in rapid overloading and shredding of the filter by high-velocity particles projected into the inlet after rebound from the surface being blasted. Because of this problem, we recommend you use the BUTTON™ Aerosol Sampler to measure metal particulates during abrasive blasting. The BUTTON sampler is a reusable filter sampler designed to capture the inhalable mass during these types of operations. It has a porous curved-surface inlet and a removable cover containing evenly spaced holes that act as sampling orifices and provide multi-directional sampling capability (see Figure 6) [9-10]. The sampler is marketed by SKC®. The sampling head screws on and off to allow placement of a 25-mm sampling filter inside the sampler and subsequent removal after sampling. A flow rate of 4.0 liters per minute (lpm) is recommended for collection of the inhalable mass. The sampler is designed with a wire mesh back-up pad. This mesh causes a large pressure drop and most air sampling pumps do not have sufficient back pressure to provide the recommended 4.0 lpm flow. We recommend you remove the wire mesh contained provided with the sampler and replace it with a standard

Table 1. Recommended Sampling Methodology

Procedure	Substance	Sampling Method	Sampling Media	Sample Flow Rate (lpm)
Pre-blast preparation	Organic solvents	Variable - based on solvent composition	Variable	Variable
Abrasive blasting	Metals (inhalable)	NIOSH 7300	0.8- μ m MCE filter, "button" sampler	4.0
	Cadmium (respirable)	NIOSH 7300	0.8- μ m MCE filter, 37-mm cassette with respirable cyclone	1.7 (nylon) 2.5 (aluminum)
	Chromates	NIOSH 7600	5- μ m PVC filter, "button" sampler	4.0
Post-blast cleaning	Metals (inhalable)	NIOSH 7300	0.8- μ m MCE filter, 37-mm cassette with 15-mm hole drilled in cap or IOM sampler	2.0
	Cadmium (respirable)	NIOSH 7300	0.8- μ m MCE filter, 37-mm cassette with respirable cyclone	1.7 (nylon) 2.5 (aluminum)
	Chromates	NIOSH 7600	5.0- μ m PVC filter, 37-mm cassette with 15-mm hole drilled in cap or IOM sampler	2.0
Final finishing/clean-up	Metals (inhalable)	NIOSH 7300	0.8- μ m MCE filter, 37-mm cassette with 15-mm hole drilled in cap or IOM sampler	2.0
	Cadmium (respirable)	NIOSH 7300	0.8- μ m MCE filter, 37-mm cassette with respirable cyclone	1.7 (nylon) 2.5 (aluminum)
	Chromates	NIOSH 7600	5.0- μ m PVC filter, 37-mm cassette with 15-mm hole drilled in cap or IOM sampler	2.0

Figure 6. BUTTON™ Sampler



25-mm back-up pad. Use 25-mm 0.8- μ m mixed cellulose ester (MCE) filters as sampling media. After sampling, place the filter in a petri dish, handling it carefully so collected dusts are not dislodged and lost. Analyze the filters per NIOSH Method 7300 [11]. Request "METSCRN" on the sampling form to sample for all metals of interest, unless you are concerned with only some specific metals.

Cleaning Procedures: Post-blast cleaning and final finishing/clean-up does not experience the high velocity particulates associated with abrasive blasting, so you can use routine sampling methods instead of the BUTTON sampler if you like. The most well known and readily available inhalable mass sampler is the Institute of Occupational Medicine (IOM) sampler, also available through SKC®. It uses a 25-mm filter placed inside a removable cassette with a 15-mm inlet opening (see Figure 7). Particulates collected both on the filter and on the walls of the cassette represent the inhalable mass fraction [12]. As an alternative, you can use a 37-mm cassette with a 15-mm hole drilled in the cassette cap to simulate the collection characteristics of the IOM sampler. To reduce bias from sampler orientation, use a cassette holder designed to keep the cassette face parallel to the worker's body (see Figure 8) [13]. Use 0.8- μ m MCE filters as sampling media and sample at 2.0 lpm. Analyze with NIOSH Method 7300 as above.

Respirable Particulates

Some metals, such as cadmium, that may be present during abrasive blasting have occupational exposure limits measured as the respirable fraction. To sample for respirable mass use a respirable cyclone. The cyclone separates non-respirable particulates from the aerosol size distribution, collecting the respirable mass on a filter. The most common cyclones in use are the MSA® nylon cyclone and the SKC® aluminum cyclone. These two cyclones are slightly different in design and require different flow rates to operate properly: 1.7 lpm for the MSA nylon cyclone and 2.5 lpm for the SKC aluminum cyclone. Use a 0.8- μ m MCE filter mounted in a 37-mm cassette attached to the cyclone. Analyze according to NIOSH Method 7300.

Chromates

Sample for chromates ($[\text{CrO}_4]^{2-}$) in a similar manner as inhalable metal particulates, with the exception that analysis is done per NIOSH Method 7600 for hexavalent chromium [14]. Therefore, use the BUTTON sampler during abrasive blasting, and use either the IOM or modified 37-mm cassettes during clean-up. Use a 5.0- μ m polyvinyl chloride (PVC) filter. Sample at 4.0 lpm (BUTTON sampler) or 2.0 lpm (IOM or 37-mm cassette).

Other Considerations

There are several other considerations when performing sampling during abrasive blasting operations. Place the sampler on the *outside* of any protective equipment the worker wears. If personnel wear a blasting helmet with a shroud, ensure the samplers are not covered up by the shroud or blocked by the workers' arms. From our observations, the best place to mount the samplers is very close to the top of the shoulder away from wrinkles in the shroud. How the worker holds the blasting hose also affects appropriate sampler placement. If the worker holds the blasting nozzle over the shoulder, place the sampler so the inlet is not blocked. In some cases, the workers may blow down their coveralls with compressed air after blasting to remove dust (Note: this is an OSHA violation). Remove the samplers before this is done so that collected dust is not blown off or dislodged from the samplers.

Figure 7. IOM Sampler

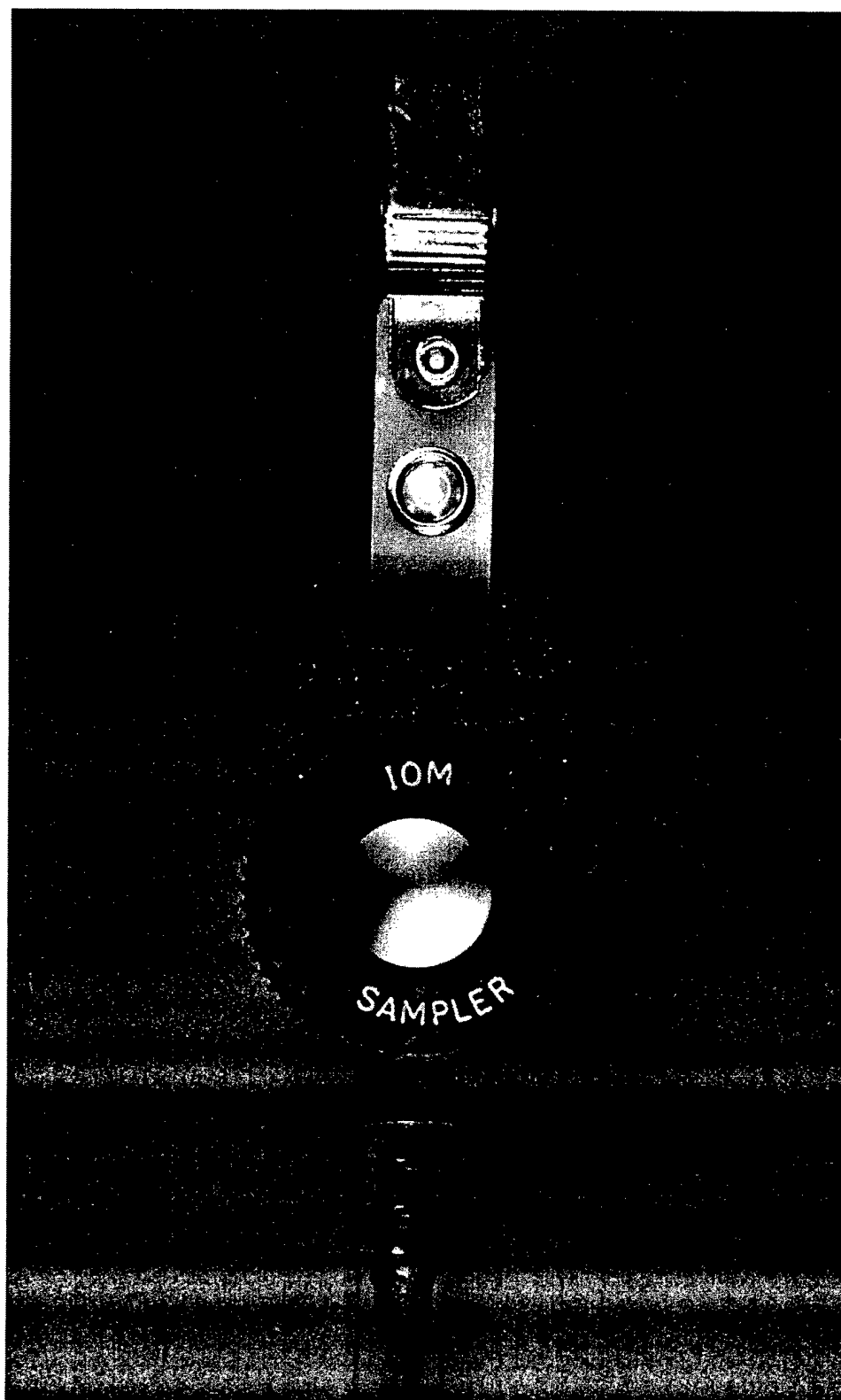
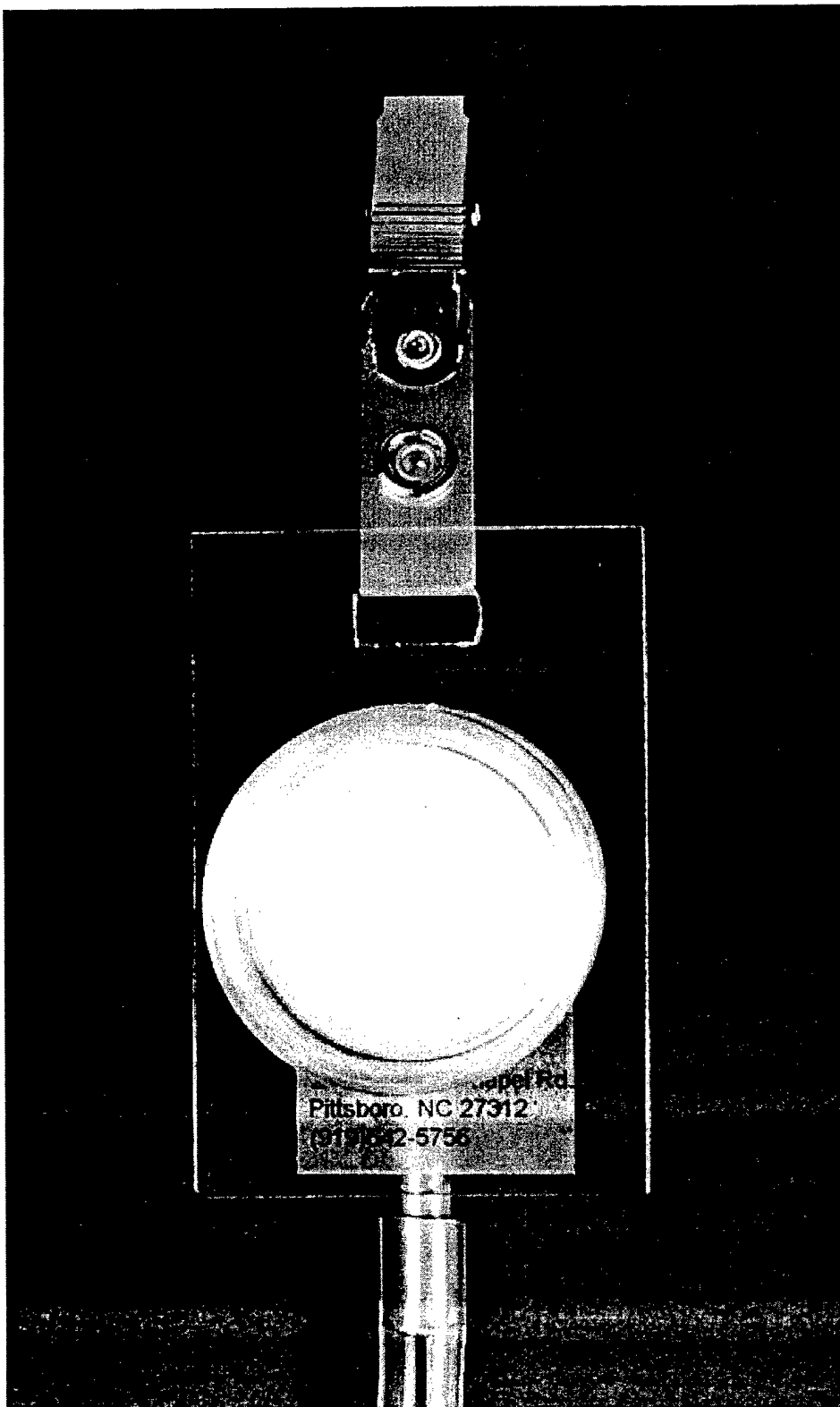


Figure 8. 37-mm Cassette with 15-mm Opening



DATA EVALUATION

Process Timelines

Sample each abrasive blasting operation separately. Sample as many workers involved in each task as possible. Make sure to record a timeline during each procedure, specifically the time the workers actually perform the procedure (task length). The task length is not necessarily the time the sampling pumps were turned on and off, since workers may take breaks or do other work during the procedure. During our evaluations, it was necessary to remove the samplers about every fifteen to twenty minutes because the filters became so heavily loaded.

Exposure Calculation

Calculate both the task exposure and the 8-hr time-weighted average (TWA) exposure for the contaminants you're interested in. The task exposure is the average concentration over the length of the task, and is useful for determining effectiveness of engineering controls and respiratory protection. For example, engineering controls that keep task exposures below the 8-hr TWA exposure limit will protect the worker even if an operation is performed for an entire eight-hour workday. Use the following equation to calculate the exposures if the lab reports results in mass (milligrams). On the other hand, if results are reported in mg/m^3 and sampling was done over the length of the task, the reported value is the task exposure.

$$\text{Task Exposure}[\text{mg}/\text{m}^3] = \frac{(\text{mg contaminant})(10^3 \text{ lit}/\text{m}^3)}{(\text{sampling rate}[\text{lit}/\text{min}])(\text{task length}[\text{min}])} \quad (1)$$

Use the following equation to calculate the 8-hr time weighted average:

$$8\text{-hr TWA} = (\text{Task Exposure}) \left(\frac{\text{task length}[\text{min}]}{480 \text{ min}} \right) \quad (2)$$

Comparison to Exposure Standards

Occupational exposure limits for the metals you'll most likely encounter during abrasive blasting are shown in Table 2 [8,15-16]. ACGIH Threshold Limit Values (TLVs), OSHA Permissible Exposure Limits (PELs), and NIOSH Recommended Exposure Limits (RELs) are shown as eight-hour time-weighted averages (TWA). The OSHA PELs are found in 29 CFR 1910.1000 and expanded standards. Some metals do not have established exposure guidelines. For most blasting procedures done in the Air Force, chromate exposures will result from strontium chromate, as this type of chromate is the most prevalent used in the last 20 years. Exterior aircraft surfaces and most aircraft parts are primed with a strontium chromate primer. Some interior aircraft parts may have been primed with a zinc chromate primer. The analytical method for chromates (NIOSH 7600) cannot differentiate among the various types of chromated compounds, so compare the 8-hr TWA to the current OEL for strontium chromate ($0.0005 \text{ mg}/\text{m}^3$) if you don't know what type of chromate the workers were exposed to.

Table 2. Exposure Limits for Substances Encountered During Abrasive Blasting (mg/m³)

Substance	8-hr TWA		
	ACGIH TLV	OSHA PEL	NIOSH REL
Metals			
Aluminum	10	15	10
Antimony	0.5	0.5	0.5
Arsenic	0.01	0.01	--
Barium	0.5	0.5	0.5
Beryllium	0.002	0.002	0.0005(C)
Boron	--	--	--
Cadmium	0.01 ^a	0.005	--
Cadmium (respirable)	0.002	--	--
Calcium	--	--	--
Chromium	0.5	1.0	0.5
Cobalt	0.02	0.1	0.05
Copper	1.0	1.0	1.0
Iron	5.0	10.0	5.0
Lead	0.05	0.05	0.1
Magnesium	--	--	--
Manganese	0.2	--	1.0
Molybdenum	10.0	15.0	--
Nickel	1.5	1.0	0.015
Potassium	--	--	--
Selenium	0.2	0.2	0.2
Silver	0.1	0.01	0.01
Sodium	--	--	--
Strontium	--	--	--
Thallium	0.1	0.1	0.1
Vanadium	--	--	--
Zinc	8.0	12.0	4.0
Zinc (respirable)	--	4.0	--
Chromates			
Strontium Chromate (as Cr)	0.0005	0.05	0.001
Zinc Chromate (as Cr)	0.01	0.05	0.001

^a inhalable fraction

VENTILATION DURING ABRASIVE BLASTING

Operational Considerations

Blasting operations generally are accomplished in some form of ventilated blasting enclosure. The primary purpose of the ventilation is to prevent the build-up of explosive dust concentrations. A blasting booth is a Class II, Division 1 environment so precautions must be taken to ensure dust concentrations are controlled [17]. A secondary benefit is capture of abraded coatings and control of contaminant levels, which a blast enclosure does a poorer job of doing, as evidenced by the exposure levels summarized in Appendix A. Outlined below are recommended procedures to evaluate the ventilation systems on both blasting cabinets and rooms. It's always a good idea to review the manufacturer's literature on the blasting booth to ensure you know exactly how the system works, as there are differences among manufacturers.

Blasting Cabinets

Abrasive blasting cabinets generally have intake vents located on top of the cabinet. These intakes are either baffled or have some sort of filter over them to prevent blast media being projected out of them. Air enters the cabinet, then is exhausted through an opening on the side of the cabinet. The exhaust duct leads to a media separator such as a cyclone, which separates the media from the abraded coatings. Air from the cyclone then passes through a filter before being exhausted into either the room or outside the facility. The first step in evaluating an abrasive blasting enclosure is to determine the air flow. There are two ways you can measure air flow (cubic feet per minute, [cfm]). The quickest and easiest way is to take face velocity measurements at the air intakes and multiply by the cross-sectional area of the openings. The more accurate way is to perform a pitot traverse in the exhaust duct. A pitot traverse is more accurate because there will be some leakage of air into the cabinet through the parts door and other openings. A pitot traverse will also allow you to determine the air velocity in the exhaust duct.

Measure the cabinet volume (measure the height from the top of the cabinet to the grate the parts sit on). Determine the number of air changes per minute (ACM) in the cabinet using the following formula:

$$ACM = \frac{\text{Air Flow (cfm)}}{\text{Volume (ft}^3\text{)}} \quad (3)$$

An ACM of 20 is recommended for blasting cabinets [18]. The exhaust duct should have a minimum duct velocity of 4000 feet per minute (fpm) to prevent settling of dust inside the duct.

Blasting Rooms

Abrasive blasting rooms are either downdraft or crossdraft design. In downdraft ventilation design, air enters through inlets in the roof of the room and exit through the floor grille. In crossdraft design, on the other hand, air enters through one side of the room (usually the door) and exits through either a plenum or opening on the other side. The best way to measure the total air flow in the room is to perform a pitot traverse in the exhaust duct. As mentioned above, sufficient ventilation is necessary to prevent a build-up of an explosive atmosphere. The ventilation rate required to prevent the build-up of an explosive

atmosphere depends on the material generation rate and the effectiveness of the ventilation system in capturing the contaminants. Determine the aerosol concentration in the room assuming steady-state conditions using the following equation:

$$Q = \frac{(G_a)(K)}{(C_a)} \quad (4)$$

where: Q = blasting booth ventilation rate (cfm)

G_a = aerosol generation rate (g/hr)

C_a = maximum allowable aerosol concentration (g/m^3)

K = ventilation mixing factor

The Industrial Ventilation Manual recommends a minimum air flow of 80 cfm per square foot of floor area for a downdraft room, and 100 cfm per square foot of wall area (room cross-sectional area) for a crossdraft room [18]. The blasting room should have an air flow equal to the higher of either equation (4) or these minimum flows. An example of how to calculate required air flow in a blasting room is shown in Appendix B. As with cabinets, the exhaust duct from the blasting room should have a minimum duct velocity of 4000 feet per minute (fpm) to prevent settling of dust inside the duct.

Pressure Characteristics

Blasting cabinets and rooms should be under negative pressure relative to the facility they're located in. Negative pressure helps contain particulates generated during the blasting procedure inside the enclosure. Perform smoke tests to qualitatively determine pressure characteristics. Blow smoke around the exterior openings of the blast enclosure with the ventilation system on. If the enclosure is under negative pressure, smoke will be drawn into the enclosure. Consider installing a manometer as an indicator that the enclosure is under negative pressure.

Filtration Systems

Filters are an integral part of the blasting enclosure's emission control system. Examine the blasting system and review the manufacturer's literature. The emission system will usually include a cyclone separator followed by a fabric filter. Check the system and determine the type of filter installed; high-efficiency particulate air (HEPA) filters are the best choice. Local environmental regulations may require them. Low to medium efficiency filters, such as the fabric pre-filters used in furnaces or HVAC systems, do not effectively capture the particulates generated during abrasive blasting [18]. To ensure proper operation of the ventilation system, filters should be routinely cleaned and/or changed. Filter cleaning and change-out schedules can be effectively monitored by use of magnehelic gauges, inclined manometers, or by establishing a routine maintenance schedule based on hours of use. A pre-filter may be necessary on the air supply or intake to the abrasive blasting enclosure to keep blast media from exiting and inadvertently exposing personnel not directly involved with the blasting procedure.

RESPIRATORY PROTECTION

Airline respirators with blasting helmets are recommended during abrasive blasting operations because of the high concentration of particulates present, the probability of air-purifying respirator filters to load quickly from the high particulate concentrations, and for the protection of the workers' head and neck regions [7]. There are several components to the breathing air system including the air supply compressor, air purification and filtration system, carbon monoxide monitor, and breathing air delivery system. Each of these components require a thorough evaluation to ensure their operability. The manufacturer's instructions and guidelines for the system offers the best source of information for proper use and evaluation of the breathing air system.

Air Supply Compressor

The air supply is the most critical portion of the breathing air system. If poor quality air is delivered to the worker, the purpose of the airline system is defeated. Evaluation of the air supply begins at the compressor used to compress and supply the air. The compressor intake should be located where there is minimal opportunity for contaminants such as vehicle exhaust to enter. The intake should be screened to minimize the potential of birds or other animals to enter the room where the compressor is located. It's best to have separate breathing air and tool air systems. A dedicated system minimizes the opportunity for entry of pneumatic tool oils into the breathing air; dedicated systems, however, are not always possible or practical in older facilities. Compressors are generally categorized as either "oil-lubricated" or "not oil-lubricated" [19]. If an oil-lubricated compressor is used, there is a possibility that the compressor will generate carbon monoxide if it overheats and the oil thermally degrades. This possibility, however, is small as most compressors will shut down below the thermal decomposition temperature of oil [20-21]. In spite of this, an oil-lubricated compressor should still have a high temperature and/or carbon monoxide alarm installed on it [19]. If an oil-lubricated compressor supplies both tool and breathing air, the hard plumbed lines should be separate and marked for identification. NIOSH recommends use of a dedicated breathing air system with a not oil-lubricated compressor during abrasive blasting [7].

Air Purification

The breathing air must have an air purification system in-line to ensure Compressed Gas Association Grade D air is delivered to the worker [22]. Grade D breathing air has the following requirements: oxygen content (v/v) of 19.5-23.5%; hydrocarbon (condensed) content of 5 mg/m³ of air or less; carbon monoxide (CO) content of 10 ppm or less; carbon dioxide content of 1,000 ppm or less; and lack of noticeable odor [19]. The purification system must have suitable in-line air-purifying sorbent beds and filters to ensure breathing air quality. The purification system will usually have several filters to collect oil mist and some moisture. These filters will be followed by a desiccant to further dry the air. A final sorbent containing a catalyst that converts carbon monoxide to carbon dioxide may be present [23]. Sorbent beds and filters need to be maintained and either replaced or refurbished periodically following the manufacturer's instructions. OSHA requires the air purification system to have a tag containing the most recent change date and the signature of the person authorized by the employer to perform the change [19]. Our evaluations showed systems frequently are not maintained properly and may even be missing some of the necessary filters [24]. Breathing air samples should be collected in evacuated compressed gas cylinders every 90 days for analysis of hydrocarbon, carbon dioxide, carbon monoxide, oxygen, and water content [22].

Carbon Monoxide Detector

Carbon monoxide detectors should be calibrated by the manufacturer or the Precision Measurement and Equipment Laboratory (PMEL) at least every 180 days and periodically checked by the user [22]. The breathing air system should have a visual or audible alarm connected to the carbon monoxide detector. The alarm should be located where workers can either see or hear it. Alarms are frequently located in inaccessible compressor locations, near the ceiling far above eye level, or completely absent. Users should periodically check the alarms.

Breathing Air Delivery System

The breathing air delivery system includes the blasting helmet, breathing tube, regulator, cooling and heating assemblies, air supply hose, and necessary couplings. NIOSH requires each manufacturer print a certification label in the instructions listing components by part number along with cautions and limitations for use [25]. Examine each of these items to ensure the shop is using proper components. One of the most important requirements is proper air flow delivery to the blasting helmet. A pressure gauge should be installed in-line with the breathing air so the worker can monitor the delivery pressure to the breathing air hose. The manufacturer's literature indicates proper input pressures. NIOSH requires a minimum airflow of 170 lpm (6 cfm) for abrasive blasting respirators [25]. We recommend you measure and verify adequate air flows into the blasting helmet. Wrap the shroud of the blasting helmet around a cylinder, such as a metal pipe, so air escapes only through the cylinder. Determine air flow by measuring air velocity and cylinder cross-sectional area:

$$\text{Flow [cfm]} = (0.9)(\text{centerline velocity [fpm]})(\text{cross-sectional area [ft}^2\text{]}) \quad (5)$$

Some manufacturers offer replaceable, peel-off visor coverings so that abrasives don't damage the clear blasting helmet visor as readily. Airline hose couplers should be incompatible with other non-breathing air and gas lines.

System Maintenance

Maintenance and monitoring of the breathing air systems is typically a joint responsibility. Civil Engineering personnel are responsible for the maintenance of the compressor systems, the permanently installed air supply lines, and alarms, while maintenance personnel are usually responsible for the operation of purification systems and carbon monoxide monitors, and collecting breathing air samples for laboratory analysis. This division of responsibility can sometimes result in lack of communication and problems not being addressed to the appropriate authority for correction. For example, problems with an air compressor or associated carbon monoxide/high temperature alarm can result in poor breathing air quality that is not conveyed to personnel using the air for their respirators. Although it may be the assigned responsibility of another duty section to maintain a portion of the breathing air system, a quality control check of all components of the breathing air system by the users of the blasting enclosure is desirable.

Respirator Protection Factors

As indicated in Appendix A, your workers may experience exposures to some metals (particularly cadmium and chromates) over occupational exposure limits. This begs the question, "Does the abrasive blasting helmet provide adequate respiratory protection?" The answer to this question depends on the assigned protection factor (APF) of the blasting helmet. Unfortunately, different organizations assign different APFs to blasting helmets, so the issue can be confusing. NIOSH assigns an APF of 25 [26], while the American National Standards Institute (ANSI) lists an APF of 1000 [27]. Why are they so different? Workplace protection factor studies, which measure contaminants both inside and outside the respirator during actual processes, indicate that a blasting helmet provides an APF of 1000 [28]. Therefore, ANSI accepts an APF of 1000. NIOSH, on the other hand, doesn't necessarily disagree that a blasting helmet will provide an APF of 1000. Their concern, however, is that the blasting helmet doesn't have a back-up in case the breathing air is cut-off. Without a back-up, the worker could be exposed to the contaminants until leaving the area. For this reason NIOSH says blasting helmets cannot have an APF greater than 25. The problem here is that when NIOSH thinks about abrasive blasting, they're thinking about continuous process lines that continue to generate contaminants if the breathing air is cut-off. This is different from almost all Air Force abrasive blasting operations, where if the air is cut-off, the worker simply stops blasting and contaminants stop being generated. In some instances, the blasting room and the air supply are interlocked, so if the air stops, the blasting process stops. So in reality an APF of 1000 is the more appropriate one to use for most Air Force blasting procedures. OSHA realized this when, in their latest update to the respiratory protection standard, they did not promulgate APFs but left it to the local industrial hygienist to determine what would be an appropriate APF based on an evaluation of the process [29].

OTHER PERSONAL PROTECTIVE EQUIPMENT

Our minimum recommended PPE requirements for abrasive blasting are shown in Table 3.

Hand Protection

Disposable nitrile rubber gloves provide adequate skin protection against metal and chromate particulates generated in abrasive blasting rooms. Workers, however, should also wear leather gloves to provide impact protection from blasting media. A disposable nitrile glove worn underneath a leather glove provides the best protection for workers. The worker can throw the disposable glove away, while reusing the leather glove.

Other Equipment

Workers should wear cotton or tyvek® coveralls to reduce skin contact with metal-containing dusts. Disposable coveralls are preferred because workers can discard them after use; reusable cotton coveralls require laundering, which can lead to metal exposures to laundry personnel. Workers require hearing protection whenever blasting enclosures are in operation, as blasting booths and rooms generate hazardous noise levels [7]. Workers must wear safety glasses whenever there is the potential for suspension of particulates, such as refilling the blast media storage hopper. If the workers use the blast hose and nozzle draped over the shoulder (as compared to holding at their sides), consider the use of leather shoulder covers. Covers provide added worker protection and comfort. Workers must wear safety toe boots during all abrasive blasting procedures because of the potential for heavy aircraft parts and objects falling to the floor.

Storage

Workers should properly store and maintain their protective equipment. Coveralls, gloves, and gauntlets should be stored away from dust sources and periodically cleaned and replaced. The blasting helmet is best stored by hanging in order to avoid damage to the shroud.

Table 3. Minimum Recommended Controls and PPE for Abrasive Blasting Operations^a

Operation	Engineering Controls	Personal Protective Equipment					
		Respiratory	Hand	Ear	Eye	Body	Foot
Refilling of blast media	None	None	None	Ear plugs ^b	Safety glasses or goggles	Tyvek or cotton coveralls	Safety toe boots
Abrasive blasting (cabinets)	Abrasive blast cabinet	None	Blasting cabinet gloves	Ear plugs	Safety glasses or goggles	Tyvek or cotton coveralls	Safety toe boots
Abrasive blasting (rooms)	Abrasive blast room	Airline with abrasive blasting helmet	Leather and disposable nitrile	Ear plugs	None	Tyvek or cotton coveralls; leather cover ^c	Safety toe boots
Post-blast cleaning (cabinets)	Abrasive blast cabinet	None	Blasting cabinet gloves	Ear plugs	Safety glasses or goggles	Tyvek or cotton coveralls	Safety toe boots
Post-blast cleaning (rooms)	Abrasive blast room	Airline with abrasive blasting helmet	Leather and disposable nitrile	Ear plugs	None	Tyvek or cotton coveralls	Safety toe boots
Final finishing/clean-up	HEPA vacuum	None	None	Ear plugs ^b	None	Tyvek or cotton coveralls	Safety toe boots

^aLocal Bioenvironmental Engineer may recommend more restrictive controls or PPE based on exposure monitoring

^bWhen noise levels exceed 85 dBA

^cWhen blast nozzles and hoses are draped over the shoulder

WORKPLACE PRACTICES

Factors Influencing Dust Generation

Blasting media size, distance the blast nozzle is from the part being blasted, and blast nozzle pressure influence dust generation rates and worker breathing zone concentrations. Blasting nozzle distance (stand-off distance) varies depending on the surface or part blasted and the type of media used [1]. Typical stand-off distances in blasting rooms are twelve to eighteen inches from the part. Some workers hold the blasting nozzle over their shoulder while others hold the nozzle at the waist. Holding the blast nozzle over the shoulder causes the worker's breathing zone to be closer to the surface being blasted, probably resulting in higher exposures than when held at the side. More visible dust is generated when workers use higher blast nozzle pressures (40-60 psi) than lower nozzle pressures (20-30 psi).

Parts Positioning

Dust control is more easily achieved when the worker positions parts being blasted close to the exhaust air duct. When parts are close to the exhaust duct, particulates are more readily entrained in the air flow and do not recirculate inside the blast enclosure as readily. Workers should also blast with the air flow in a crossdraft blasting room to their side or back to minimize dust traveling past their breathing zone before being exhausted.

Control of Blasting Dust

It's important to contain as much dust as possible within the blasting enclosure. The main concern is transfer of dust into administrative areas, break rooms, and other areas where personnel not directly involved in the procedure may receive incidental exposures to metals and chromates. It's especially important not to carry metal-containing dusts home to family members. Workers should remove their coveralls or use a vacuum equipped with a HEPA filter prior to exiting the blasting enclosure. Blow-down of personnel with compressed is not an approved method of dust removal. Personnel not involved with the operation should not enter the area without proper protective equipment. Workers should practice good personal hygiene; wash hands and face after blasting to remove contaminants.

Dust Removal and Clean-Up

Dust removal from aircraft, parts, or support equipment after completion of blasting using is acceptable but not ideal. (Note: it is a violation of the OSHA cadmium and lead standards to use compressed air to remove cadmium and lead from surfaces unless used in conjunction with some sort of ventilation.) Compressed air resuspends dusts and worker exposures could be similar to those found during the blasting operation itself. When areas around or in the blast enclosures require cleaning, HEPA vacuums are preferred over dry wiping or sweeping, both of which increase the potential for worker exposures from dust resuspension. HEPA vacuums remove dusts as effectively and with less exposure to personnel than other methods. HEPA vacuums may also be used to clean out blast grit screens and traps.

MISCELLANEOUS INFORMATION

Safety Hazards

There are numerous safety hazards involved with abrasive blasting operations. Because of the potential for explosive atmospheres, any electrical equipment must meet Class II, Division 1 requirements [17]. All electrical fixtures inside the blasting cabinet or room must be explosion-proof. Consult with the Fire Department before recommending any modifications to a blasting enclosure. Blast nozzles incorporate kill switches that turn off the media if the nozzle is dropped. Air Force personnel have been injured when the kill switch on the blast nozzle did not work. Ensure all kill switches work properly. Blast enclosures are usually equipped with an interlock system that shuts off the blasting nozzle when the blast enclosure door is opened during blasting. Check the interlocks to ensure they are working properly. Blast hoses can rupture from continual wearing of the blast media on the inside of the rubber hose. Workers should thoroughly inspect blast hoses before use. Look at blast hoses during your annual shop surveys. Pay particular attention to locations where the hose bends or rests on the floor [7]. The blast hose exterior can be reinforced with a metal mesh to reduce the chance of rupture. Complete a full evaluation of the breathing air system to ensure airline hose couplings are not compatible with other gas lines.

Ergonomic Hazards

Workers involved with abrasive blasting typically complain about discomfort or stiffness in the hands, wrists, arms, shoulders, neck, and back. Some of the reasons for these problems and ways to alleviate them are outlined below [30].

Blasting Cabinets: Shoulder and neck problems result from arm portals and viewing windows being too high or too low, and workers having to hold parts while blasting. Provide a height-adjustable platform or stool for different sized workers, or adjust the height of the parts inside the cabinet. Either clamp the parts to stabilize them or place them on a rotating surface. Hand, wrist, and arm problems result from inadequate grip surfaces for the blast nozzle and vibration from the nozzle. The best way to resolve these problems is a nozzle support that allows the operator to guide it without applying a large amount of force. This may not be practical without a major modification of the cabinet, so incorporate rest pauses during blasting to minimize the effects.

Blasting Rooms: Shoulder, neck and back problems result from the worker assuming static and awkward work positions while blasting under aircraft wings and fuselages, the need to rotate smaller workpieces during blasting, and the force required to hold and control the blasting nozzle. The blasting nozzles used in blasting rooms provide a higher media feed rate than blasting cabinets, and therefore are larger and heavier than those used in cabinets. Provide workers with mobile and adjustable support stands to reduce static muscle loading while working under or adjacent to aircraft or large components. Provide a turntable to allow rotation of smaller parts. Support the blasting nozzle with a hanger or hook to keep it off the floor. If the worker puts the hose over the shoulder, use a leather cover for protection. Hand, wrist, and arm problems result from poor nozzle handle design (poor trigger location and too large of a nozzle diameter), the requirement to continuously hold the trigger during blasting, and nozzle vibration. The triggers for some nozzles require the workers to bend their wrists in awkward positions; supporting the blast nozzle can alleviate some of the effects. Outside of procuring more ergonomic blast nozzles, consider extending the trigger or modifying the handle on the existing nozzle, if feasible and safe. Again, incorporate rest pauses to minimize ergonomic hazards.

Hazardous Waste Minimization

Abrasive blasting is an excellent and rapid method for finish system removal, but generates waste that is frequently classified as a hazardous waste because of heavy metal contamination (lead, cadmium, or chromium). One way to avoid hazardous waste generation is to recycle the blast media. Spent plastic media can be recycled, without processing, by making cultured marble products. Since spent plastic media is an ingredient in an industrial process that makes a product, and is not being reclaimed (processed), the Environmental Protection Agency (EPA) doesn't consider it a solid waste. It therefore isn't a hazardous waste under EPA Resource Conservation and Recovery Act (RCRA) regulations. According to Title 40 CFR, Part 261.1, the EPA considers a material reclaimed if it is either processed to recover a usable product or if it is regenerated. If you recycle spent plastic media as an ingredient in an industrial process without reclamation, then it doesn't require management as a hazardous waste. However, if you recycle plastic media in a manner that doesn't meet the regulatory requirements addressed above, you may need to manage it as a hazardous waste. Please keep in mind that while the plastic media may not be a hazardous waste, the Department of Transportation may still classify it as a hazardous material under their regulations because of cadmium content.

Posting of the Blasting Area

Exposures above the OSHA Permissible Exposure Limit for cadmium and lead are common during blasting. For OSHA compliance purposes, supervisors should keep records of which workers perform abrasive blasting operations. Because cadmium and lead are regulated metals that have OSHA expanded standards, posting of the blasting area is required if exposures exceed the PELs [31-32]. Exposures above the cadmium PEL require the following warning sign:

<p>DANGER CADMIUM CANCER HAZARD CAN CAUSE LUNG AND KIDNEY DISEASE AUTHORIZED PERSONNEL ONLY RESPIRATORS REQUIRED IN THIS AREA</p>

Exposures above the lead PEL require this warning sign:

<p>WARNING LEAD WORK AREA POISON NO SMOKING OR EATING</p>

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APPENDIX A – FIELD SURVEY RESULTS

Survey Locations

Field studies were completed in blasting rooms at Robins, Kelly, Hill, and Mountain Home AFBs. The locations were chosen to give a good representation of the types of blasting operations performed throughout the Air Force. The results from the specific bases are discussed in the individual consultative letters [33-36]. At the ALC bases workers spent up to six hours daily involved with some abrasive blasting procedure. At the field unit level, the time spent blasting was approximately four hours in length.

Results

Table A-1 summarizes personal exposures to metals and chromates during abrasive blasting. Exposures are calculated as a task exposure (average concentration over the length of the task). The data was approximately lognormally distributed; means and 95% confidence limits were determined from Land's procedure for calculating exact confidence intervals around the mean of lognormally distributed data [37]. 95% upper confidence limits (UCLs) exceed the ACGIH TLV-TWA for arsenic, barium, cadmium, lead, and hexavalent chromium (when compared to the TLV for strontium chromate). The data is shown graphically in Figure A-1; error bars represent 95% UCLs.

Table A-2 indicates, for 10 different types of blasting tasks, the type of material blasted, the blast media, and whether the surface was primed, painted, or plated. Figures A-2 through A-4 present the 8-hr TWA results, by task, for lead, cadmium, and hexavalent chromium. Error bars represent the standard error of the means. Three of the 10 tasks exceed the TLV/PEL for lead. Eight tasks exceed the TLV for cadmium; 9 tasks are above the PEL for cadmium. All tasks exceed the TLV for strontium chromate, while 6 are above the PEL for Cr[VI].

Table A-1. Worker Exposures During Abrasive Blasting (Task Exposures, mg/m³)

Substance	Sample Number	Range	Mean	95% Confidence Limits	UCL > OEL?
Aluminum	68	0.006 - 2.77	0.141	(0.102, 0.227)	No
Antimony	68	0.003 - 0.039	0.011	(0.010, 0.124)	No
Arsenic	68	<0.001 - 0.039	0.012	(0.010, 0.013)	Yes
Barium	68	0.01 - 4.67	0.467	(0.286, 1.30)	Yes
Beryllium	68	<0.001 - .004	<0.001	--	No
Boron	35	0.006 - 0.053	0.023	(0.021, 0.027)	--
Cadmium ^a	68	<0.001 - 2.46	0.222	(0.134, 0.661)	Yes
Calcium	68	0.003 - 1.64	0.197	(0.151, 0.288)	--
Chromium, Hexavalent ^b	77	<0.001 - 0.823	0.130	(0.095, 0.205)	Yes ^d
Chromium, Total ^c	68	0.006 - 0.725	0.078	(0.061, 0.111)	No
Cobalt	68	0.001 - 0.028	0.005	(0.004, 0.005)	No
Copper	68	<0.001 - 0.129	0.007	(0.006, 0.010)	No
Iron	68	0.004 - 4.61	0.291	(0.202, 0.522)	No
Lead	68	0.002 - 0.638	0.050	(0.036, 0.081)	Yes
Magnesium	68	0.003 - 0.260	0.053	(0.047, 0.062)	--
Manganese	68	0.002 - 0.135	0.008	(0.007, 0.010)	No
Molybdenum	68	0.002 - 0.020	0.005	(0.005, 0.006)	No
Nickel	68	<0.001 - 0.066	0.007	(0.006, 0.009)	No
Potassium	68	0.016 - 0.160	0.049	(0.045, 0.055)	--
Selenium	68	0.003 - 0.039	0.011	(0.011, 0.013)	No
Silver	68	<0.001 - 0.021	0.001	(0.001, 0.001)	No
Sodium	68	0.014 - 0.659	0.079	(0.066, 0.097)	--
Strontium	68	0.001 - 0.711	0.129	(0.090, 0.231)	--
Thallium	68	0.003 - 0.039	0.011	(0.010, 0.012)	No
Vanadium	68	0.001 - 0.016	0.005	(0.004, 0.005)	--
Zinc	68	0.001 - 0.441	0.07	(0.053, 0.104)	No

^a inhalable fraction

^bNIOSH Method 7600

^cNIOSH Method 7300

^dCompared to strontium chromate TLV-TWA

Table A-2. Abrasive Blasting Tasks Observed

Task Category	Material	Blast Media	Primed?	Painted?	Plated?	Number of Samples	
						Metals	Cr[VI]
1	Steel	Glass bead	No	No	No	4	5
2	Steel	Aluminum oxide	No	No	No	3	4
3	Steel	Glass bead	Yes	Yes	No	14	21
4	Steel	Plastic	Yes	Yes	Yes ^a	4	3
5	Steel	Plastic	Yes	Yes	No	17	17
6	Graphite Composite	Plastic	Yes	Yes	No	4	5
7	Aluminum	Walnut shell	Yes	Yes	No	1	1
8	Aluminum	Plastic	Yes	No	No	9	9
9	Aluminum	Plastic	Yes	Yes	No	6	7
10	Aluminum	Plastic	No	No	No	7	5

^aCadmium plated. Cadmium-plated rivets or small cadmium-plated sections were present during other tasks

Figure A-1. Distribution of Task Exposures to Metals

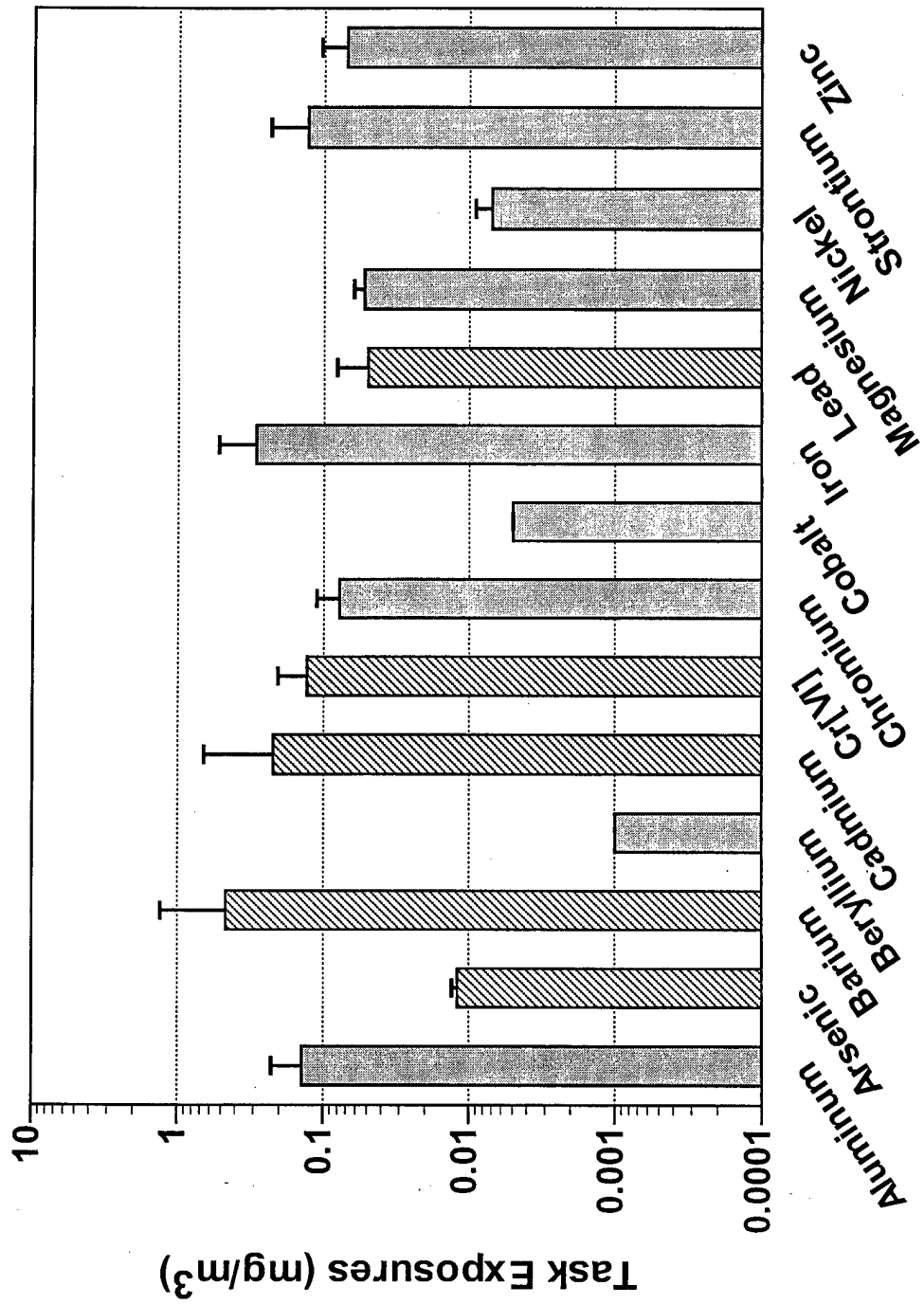


Figure A-2. Distribution of 8-hr TWA Cadmium Exposures

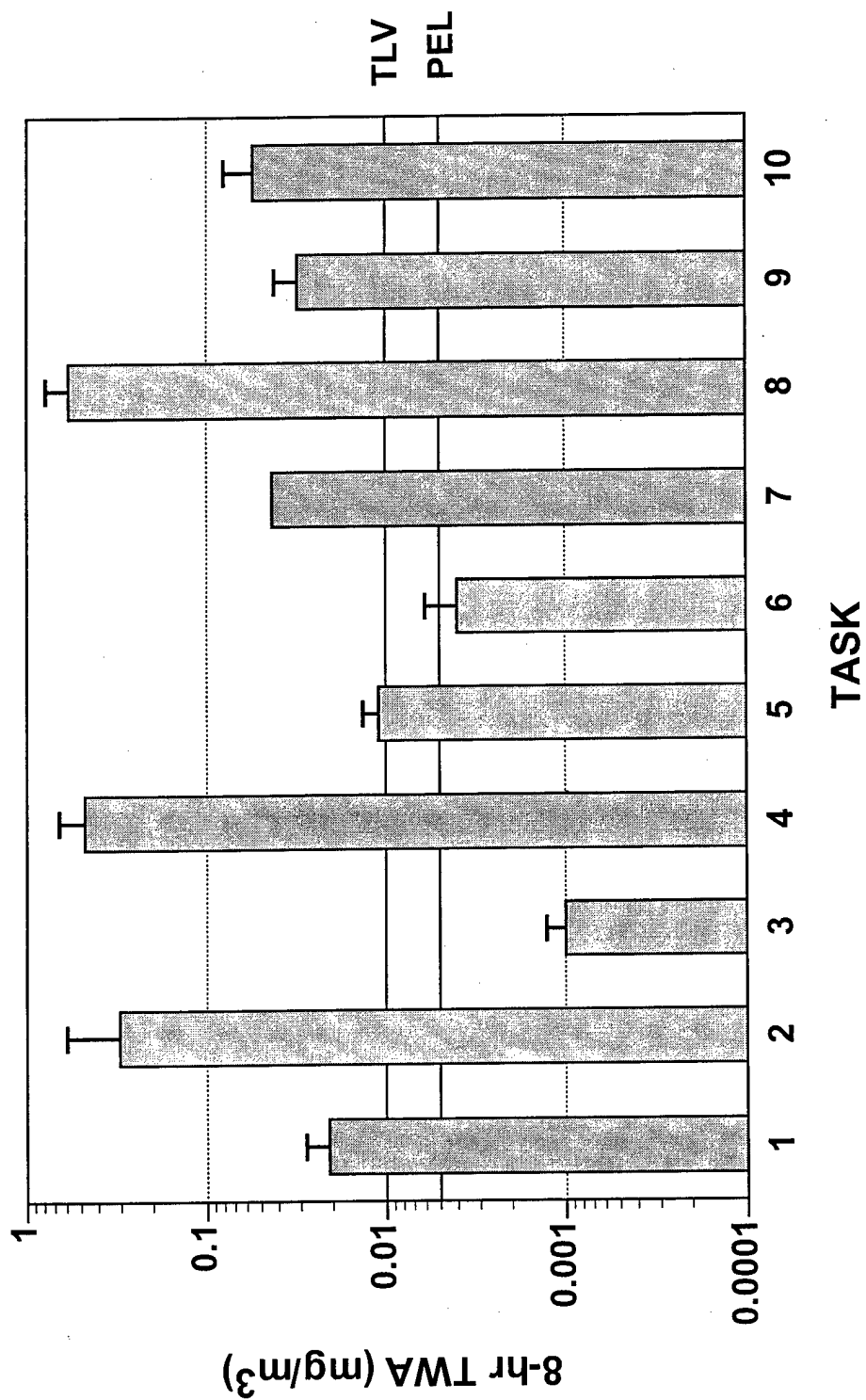


Figure A-3. Distribution of 8-hr TWA Lead Exposures

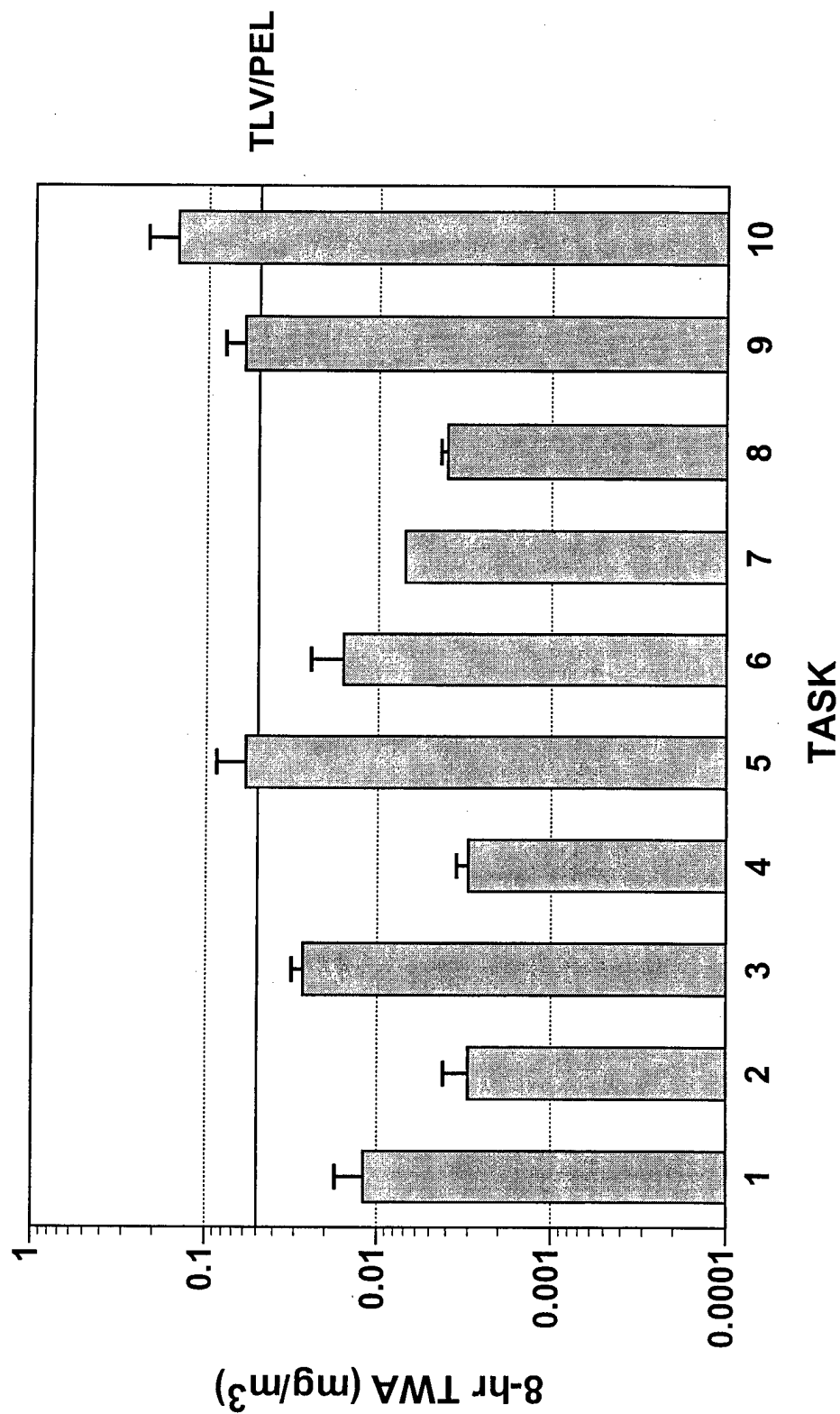
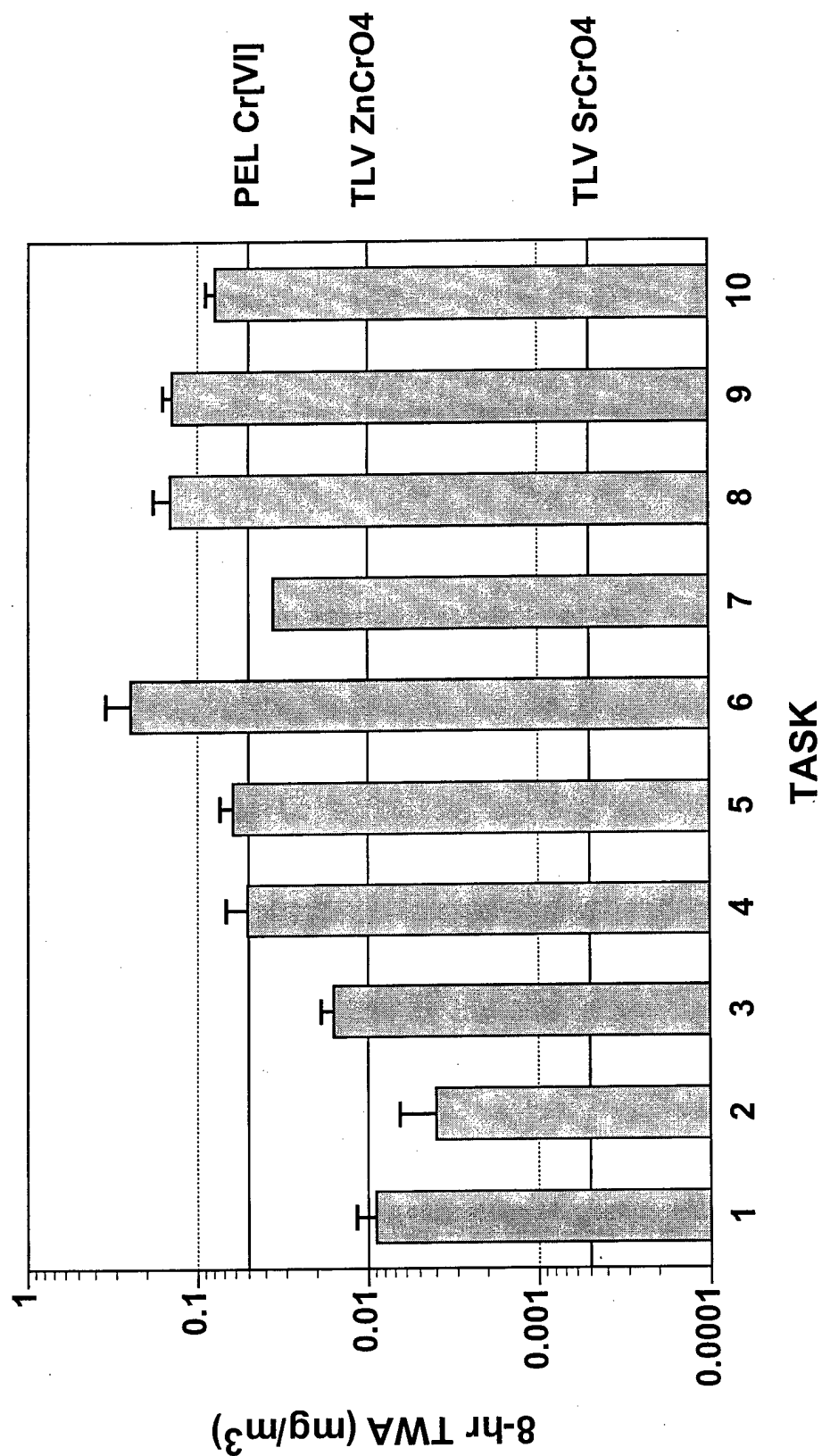


Figure A-4. Distribution of 8-hr TWA Hexavalent Chromium Exposures



APPENDIX B – ABRASIVE BLASTING ROOM VENTILATION REQUIREMENTS

Abrasive blasting operations must be adequately ventilated to prevent the build-up of explosive concentrations of dusts. The ventilation rate required to prevent an explosive atmosphere depends on the materials involved, their generation rate, and the effectiveness of the ventilation system in capturing the contaminants. The following is an example calculation on how to determine necessary ventilation rates.

Aerosol Generation Rate

The first step is to determine the amount of particulates being introduced into the blast enclosure (G_a). You can estimate the particulate quantity by asking the workers how much media they use for a particular work task. Then time the task and determine the rate of particulate generation rate. Another method is to determine the blast nozzle pressure and estimate the media feed rate of the blasting nozzle. The blast nozzle manufacturer may have tables of nozzle feed rate versus nozzle pressure [38]. Some aircraft technical orders will also specify acceptable media feed rates. For example, at one Air Force base, at a nozzle pressure of 25 psi, the feed rate for a specific type of nozzle is 375 lb/hr. The worker blasts for 30 minutes of every hour in the blast room. The aerosol generation rate in this case is:

$$\begin{aligned} G_a &= (0.5)(375 \text{ lb/hr})(454 \text{ g/lb}) \\ &= 85,125 \text{ g/hr} \end{aligned}$$

Maximum Allowable Aerosol Concentration

Any oxidizable material, including all organic materials and some inorganic compounds and metals, will burn if present as an aerosol at a sufficiently high concentration. These concentrations are usually in the range of 20-100 g/m³ [39]. Therefore, concentrations of aerosols (C_a) in blasting rooms should be kept below 20 g/m³.

Ventilation Mixing Factor

The ventilation mixing factor (K) accounts for imperfect mixing or distribution of the contaminant within the ventilated space. K generally ranges from 1 to 10. It takes judgement to determine an appropriate value of K . The K factor depends on the efficiency of air mixing and distribution of make-up air; the toxicity of the contaminants; and location of worker relative to the source of contamination [18]. You probably shouldn't use a K factor much less than 5 for an abrasive blast room because of the high toxicity of some of the metals generated during the process. Crossflow systems will probably have a higher K factor than downdraft systems, as downdraft systems tend to control contaminants better through the assistance of gravity.

Calculated Ventilation Requirement

Suppose we want to determine the minimum acceptable ventilation (Q) for a crossflow abrasive blast room used to strip aircraft parts. The room measures 30 ft in length, 20 feet in width, and 10 feet in

height. Assuming the blast media usage rates described above (85,125 g/hr), and a K value of 10, from equation (4):

$$\begin{aligned} Q &= \frac{(G_a)(K)}{(C_a)} \\ &= \frac{(85,125 \text{ g/hr})(10)(35.31 \text{ ft}^3/\text{m}^3)}{(20 \text{ g/m}^3)(60 \text{ min/hr})} \\ &= 25,050 \text{ cfm} \end{aligned}$$

The Industrial Ventilation manual recommends a minimum of 100 cfm per square foot of wall area (they mean the wall where the air exhausts out of the room) [18]. The booth we're considering has a wall area of 20 ft X 10 ft, or 200 ft², so the IV Manual recommends a minimum of 20,000 cfm. The calculated 25,050 cfm is higher than the minimum of 20,000 cfm for abrasive blasting. Therefore, the ventilation system should have at least 25,000 cfm.